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COMPUTER AIDED SELF-FORGING FRAGMENT DESIGN.(U)

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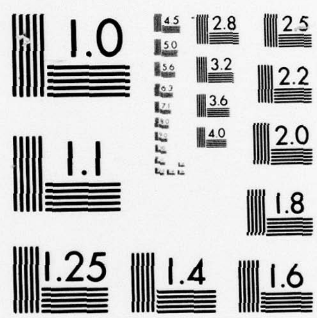

MICROCOPY RESOLUTION TEST CHART
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(6) COMPUTER AIDED SELF-FORGING FRAGMENT DESIGN,

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A number of proposed warhead concepts require an explosive charge which is detonated at a long distance from the target to form a heavy, high velocity fragment which acts as a kinetic energy penetrator to defeat armor. Two such concepts are STAFF ~~(Ref 1)~~ and SADARM ~~(Ref 2),~~ which are envisioned to attack tanks from the top, where the armor is relatively thin. A charge design which can accomplish this task is that known as the "self-forging fragment (SFF)" device or as the "Projectile-forming charge (P-charge)." In contrast to a conventional conical shaped charge which produces a jet having a tip velocity of up to 10 km/s and is capable of perforating very thick armor at short standoff distance, a SFF device forms its liner into a single slug or fragment which remains in one piece as it flies over a trajectory of 100 meters or more at a velocity approaching 3 km/s. While the depth of penetration achievable by a SFF is much less than that of a conventional jet forming shaped charge operating at short standoff distance, its performance at very long standoff is only slightly degraded by its loss of velocity due to air drag. SFF devices are the only chemical energy warheads capable of significant effect at standoff distances exceeding several dozen calibers. conclusions

Designing a SFF device is not an easy task, since the liner must be contoured so that the explosive impulse forms it into a slug which has a very low velocity gradient, otherwise it will be pulled apart. Conceptually the job is like forming a cannon ball from a sheet of material with one blow of a hammer, without a die. At ARRADCOM's Large Caliber Weapons Systems Laboratory, the HEMP computer code has been developed to serve as an effective design tool to simplify this task considerably. Using this code, warheads

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for the STAFF and SADARM concepts have been designed which successfully form into single compact slugs that are effective against armor at extremely long standoff.

The HEMP Computer Code

The computer code used for modelling the various self-forging fragment configurations is an especially modified version of the HEMP ("Hydrodynamic Elastic Magneto Plastic") program (Ref 3 and 4). This is a general purpose LaGrangian two dimensional finite-difference code developed by Mark Wilkins of the Lawrence Livermore Laboratory and widely used by the Department of Defense for munitions problems. Given a numerical grid representing the initial geometry, together with material and explosive properties (Refs 5 and 6), this code solves the equations of motion iteratively along with the equations of state to determine the deformation of the liner in response to the pressure exerted on it by the detonation products. Figure 1 shows a typical grid describing a SFF device, actually an explosive ordnance disposal item known as a "Ballistic Disc" designed (experimentally) by the late Seymour Kronman of ARRADCOM's Ballistic Research Laboratory. Initially it was not possible to run this or any other SFF problem beyond twenty or thirty microseconds without resorting to very coarse gridding and resultant loss of accuracy. This was due to a thinning out of the liner edge, which resulted in the reduction of the integration time step to an unreasonably small value to preserve computational stability. (See Figure 2.)

A modification was introduced into the code to drop this distorted region out of the problem at the appropriate time (one to three microseconds after the detonation wave strikes the liner edge). This enables the computation to resume with a reasonable time step.

This dropping procedure is performed "on the fly," that is, by including a simple instruction to ignore the distorted liner edge for the remainder of the computation. This replaces an earlier, somewhat timeconsuming method of stopping the program, creating a restart file, operating on the restart file with a rezoning computer program, and then restarting the HEMP calculation from the modified file. In practice, for finely gridded liners, it may be necessary to drop out the liner edge two or three times successively. It should be noted that this part of the liner actually does break off into a ring of fragments in test firings, so that the part that remains in the computation is representative of the part that contributes to the actual fragment or slug. Figure 3 shows a HEMP

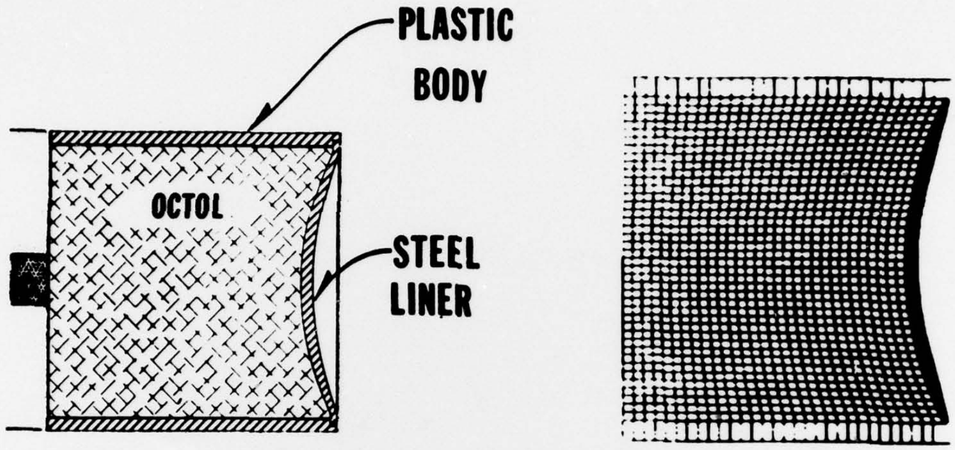

Fig 1 Kronman's ballistic disc device and HEMP numerical grid representing it

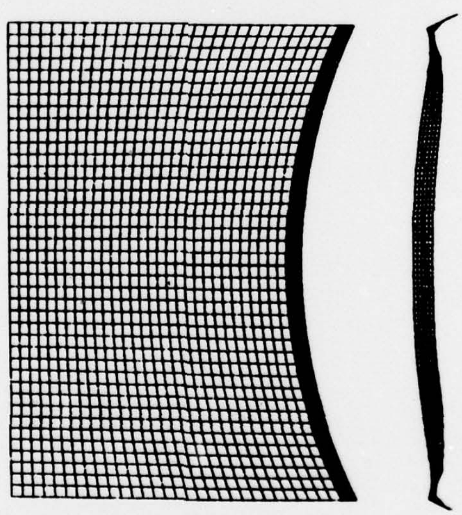

Fig 2 HEMP solution of SFF problem which stopped due to distortion of the liner edge

computation of the Kronman ballistic disc device, together with a flash x-ray of the resulting fragment. The modified code was first used to run a number of SADARM problems in conjunction with an on going experimental program (Ref 7). Extremely good agreement between computed and actual fragment shapes was obtained. With this and other comparisons completed, it was felt that the code could be used as a reliable design tool.

Additional modifications were added to the code to improve its efficiency in execution and its flexibility in use. The slide line routines were modified to improve efficiency by using vector cross products instead of trigonometric functions, and to improve the accuracy of the velocity calculations. Major reorganization of the memory management allowed the code to run fairly large problems (up to 2600 zones) in core on ARRADCOM's CDC 6600 computer, which has 240 000 octal (81 920 decimal) core locations available. Larger problems require the use of disc, which considerably increases the turnaround time for a computation. SFF problems are typically gridded with 40x5 zones in the liner and 20x30 zones in the explosive charge, and run at about one second of central processor time per iteration. On the order of 20 iterations are required for each microsecond of the

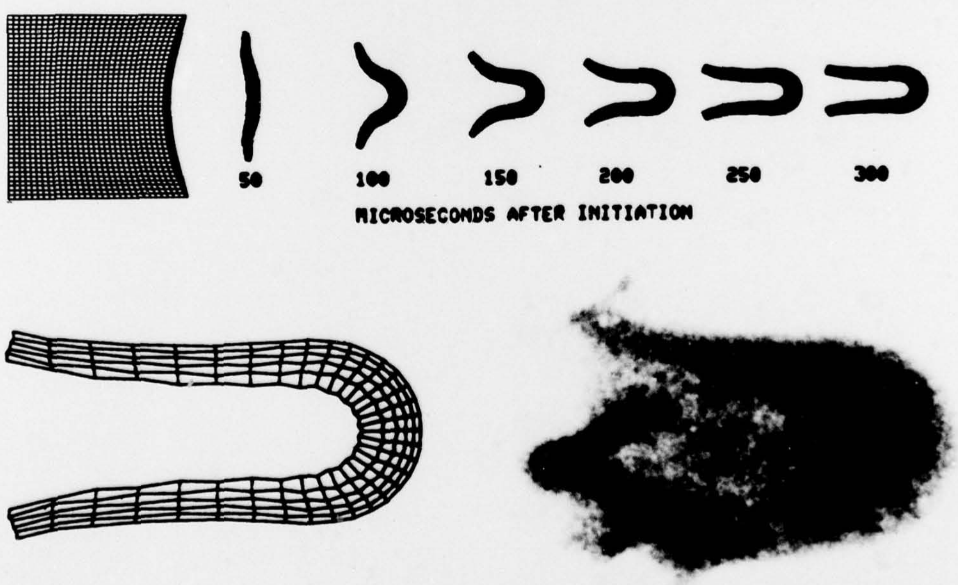

Fig 3 HEMP solution for Kronman's ballistic disc and flash x-ray of fragment

solution. At 40 or 50 microseconds, when the detonation pressure has decreased to a very low value, the explosive region can be dropped from the problem and the liner run alone to its final configuration. This saves a considerable amount of computer time and memory with negligible effect on the calculated fragment shape and velocity. By 300 microseconds the elements of the liner have stopped relative movement if they are going to stop at all. A typical HEMP run to 300 microseconds requires 15 to 40 minutes of computer time on the CDC 6600 machine.

SADARM Liner Design

SADARM ("Sense and Destroy Armor") is a warhead concept in which an artillery round ejects several submunitions in the air above tank targets. Each submunition hangs from a spinning vortex ring parachute. When a sensor detects a target, the explosive warhead detonates, sending a self-forging fragment on its way to (and presumably through) the top of the tank.

The SADARM tests described in Reference 7 were performed using a charge with explosive length to diameter ratio of 1. In the actual system configuration, it has been determined that there is only room for a warhead whose L/D ratio is 0.7. Accordingly, the HEMP code was used to design a liner whose performance would be optimized for this charge configuration. Although the earlier study used steel liners, it was decided to use copper liners here because of its greater density and because of its availability relative to the special steel previously required. Copper is less forgiving of velocity gradients than some very ductile steels, but it was hoped that the HEMP code could be used to design a liner with very little velocity gradient.

Because the hyperbolic liners used in the earlier work had produced tumbling fragments, it was decided to try to design two types of liners: one which produces a spheroidal fragment whose performance should be relatively unaffected by tumbling, and one which produces a rod-shaped fragment, flared at the rear, which might fly stably.

Based on some tests in which charges were deliberately designed to invert their liners without collapsing fully (Fig 4), the required dynamic material properties for copper were deduced. Although the handbook value of the yield strength of the copper is only 70 MPa, work hardening to 220 MPa, the tests indicated that in this dynamic environment a value of 300 MPa is more appropriate.

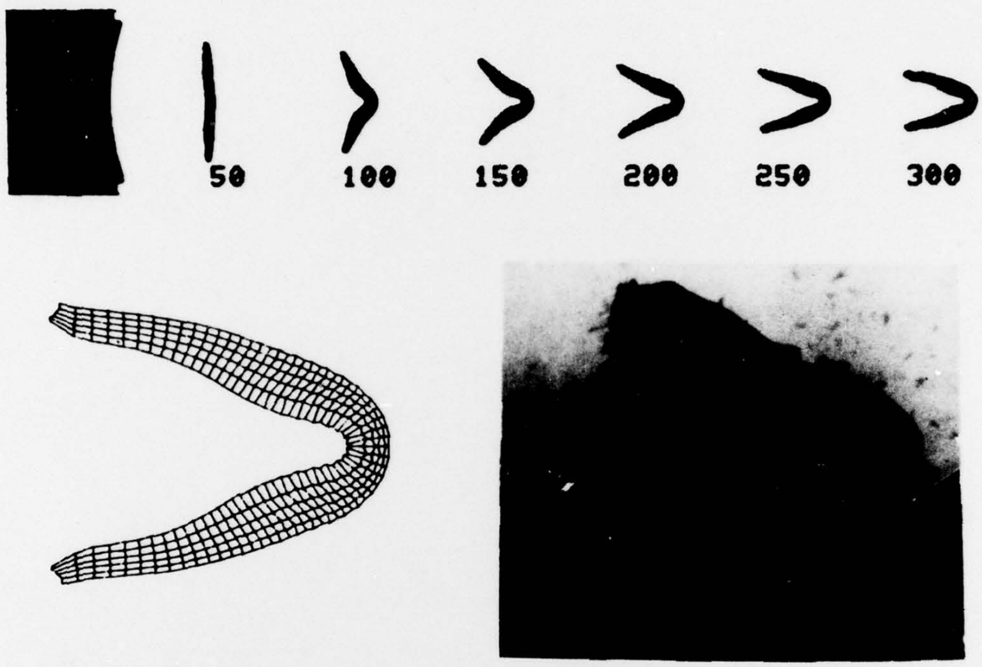

Fig 4 HEMP solution and flash x-ray of copper plate bending test

Fig 5 HEMP solution and radiograph of SADARM warhead designed to produce a spheroidal fragment

This value is reached so quickly that HEMP solutions using work hardening and those using only elastic-perfectly plastic formulations are quite similar. The latter formulation was used for the remainder of the study because it consumes less computer resources.

The solution producing a spheroidal fragment is shown in Figure 5, along with a flash x-ray of the actual fragment produced by a test charge. Excellent agreement between prediction and experiment may be noted.

The attempt to produce a flared copper rod was somewhat disappointing, as shown in Figure 6. Although the test charge shown in Figure 4 produced a single copper fragment, the slightly more severe deformation encountered here caused the formed rod to segment into several pieces. It was possible, however, to form a flared rod of steel (Fig 7). ARRADCOM's HEMP code at present has no fracture criteria built in, primarily because of a lack of raw data. It is hoped that, with further experience, it will be possible to predict the occurrence of fracture in a SFF by monitoring the calculated triaxial strain.

<u>STAFF Liner Design</u>

STAFF ("Smart Target Activated Fire and Forget") is another type of target sensing unguided munition. In this 155 mm device, two double ended self-forging fragment warheads will be mounted transversely within a spinning projectile. When the projectile senses that it is above a target, the warheads will be detonated so as to fire the self-forging fragments downward through the top of the target.

HEMP was used as the design tool from the very beginning of this project. The code was used to find the optimum L/D ratio, cylinder wall thickness, and liner thickness, subject only to the constraints that the device had to fit crosswise in a 155 mm munition, and that kinetic energy was to be maximized. Once these were determined, the contour of the liner was designed so as to produce a spheroidal fragment. The resulting warhead configuration is shown in Figure 8. Due to the extremely short time between the receipt of funds for preliminary design work (October 1976) and the proposed concept demonstration (August 1978), there was little time to perform experimental iterations. Fortunately, the first HEMP-designed warhead did produce a spheroidal fragment which performed well against armor. The predicted and actual fragment configurations are shown in Figure 9.

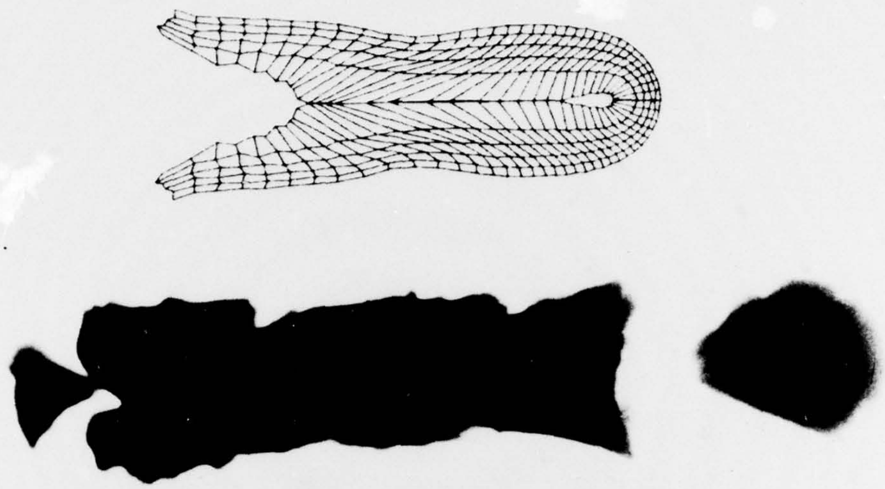

Fig 6 HEMP solution and flash x-ray for SADARM designed to produce a flared copper rod, which fractured in test firing

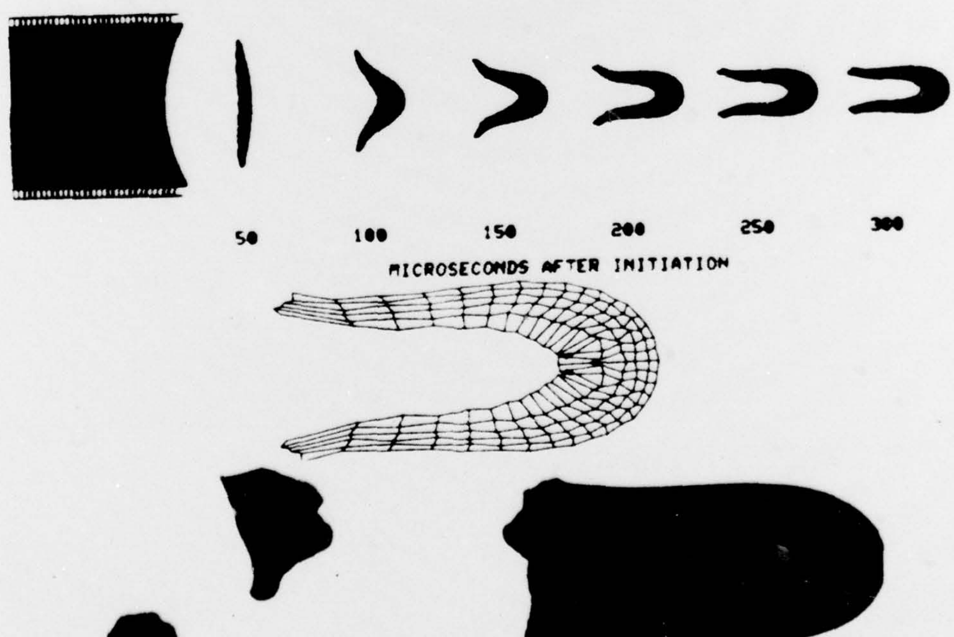

Fig 7 HEMP solution and flash x-ray for SADARM design (L/D=1) which produced a flared steel rod and did not fracture

Conclusions

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HEMP has proven to be an invaluable design tool for self-forging fragments, and has been used successfully to design warheads for the STAFF and SADARM weapon concepts.

More needs to be learned about the dynamic fracture behavior of liner materials to ensure that one-piece slugs may be reliably formed.

* (computer program)

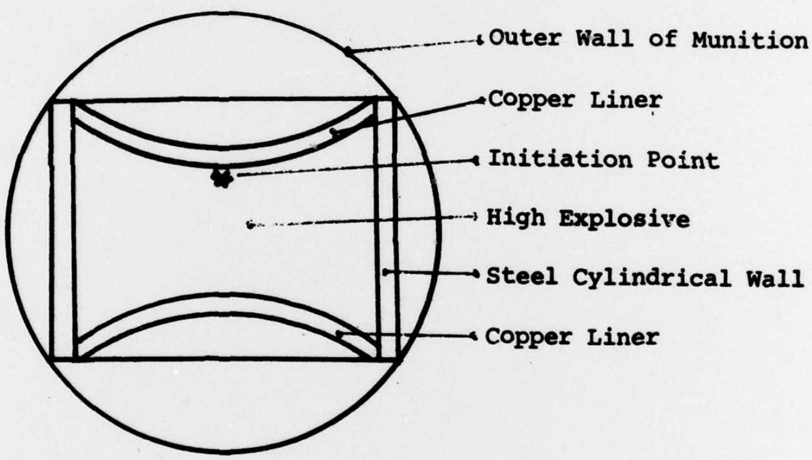

Fig 8 STAFF warhead configuration

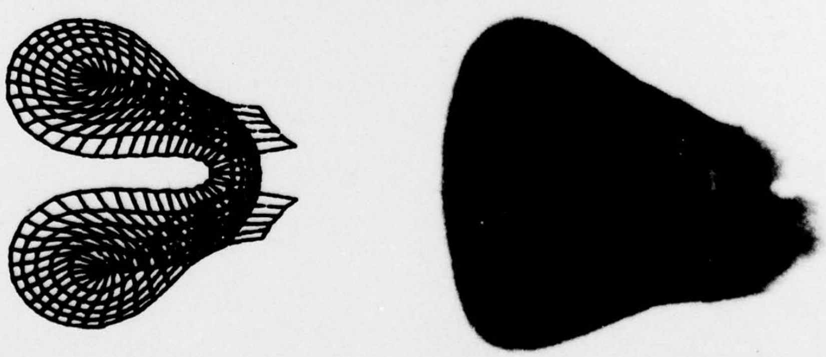

Fig 9 HEMP solution and flash x-ray of fragment from STAFF warhead

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Postscript

It is with extreme regret that I must note the accidental death on December 1, 1977, of my dear friend, research partner, and co-author, I. Peter Juriaco. Not only have his many friends at Picatinny suffered a great personal loss, but the Army has suffered a great technical loss. Pete's knowledge of detonation physics and fragmentation and his expertise in instrumentation and ultra-highspeed photography will be sorely missed for a long time.